FRICTION AND ADHESION MEASUREMENTS BETWEEN A FLUOROCARBON SURFACE AND A HYDROCARBON SURFACE IN AIR

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Introduction

Current technological devices, such as magnetic storage devices and microelectromechanical systems (MEMS) operate in a regime where the required lubricant is only a few molecular layers thick. These boundary-lubricating films are often organic monolayer films. Due to their technological importance, extensive experimental and theoretical studies of monolayer films have been conducted in recent years to determine the molecular origin of adhesion and friction, and to understand how the structure and chemistry of the monolayer film determines these properties.[1,2] In addition, these monolayer films can be used as a model system to understand the interaction between phase separated materials in bulk.

In most of the well-ordered monolayer systems studied to date, the surfaces are symmetric, i.e. a hydrocarbon monolayer is slid against another hydrocarbon monolayer of a similar packing density. In this abstract, we report the first measurements of the friction between a fluorocarbon monolayer and a hydrocarbon monolayer. Because the fluorocarbon and hydrocarbon monolayers are incompatible, one might expect there to be little interpenetration of the opposing chains. Hence, the friction between dissimilar monolayers might be expected to be less than the friction between similar monolayers. The results show that the shear stress between a hydrocarbon and fluorocarbon monolayer film is at least three times less than the friction measured between fluorocarbon/fluorocarbon or hydrocarbon/hydrocarbon monolayer films.

Experimental

A Surface Forces Apparatus (SFA) with a lateral sliding attachment was used to measure the shear forces.[3] The surfaces were prepared by Langmuir-Blodgett deposition of surfactant monolayers on molecularly smooth sheets of muscovite mica. A Nima Technology Ltd trough (Type 622) was used for the deposition. Each monolayer was prepared separately.

The fluorocarbon monolayer (FC) was prepared using a double-chained cationic surfactant (N-(α-(trimethylammonio)acetyl)-O-O'-bis(1H, 1H, 2H. 2H-perfluorodecyl)-L-glutamate chloride (TAFC) obtained from Sogo Pharmaceuticals, Ltd., Japan. TFAC was deposited onto mica from an aqueous subphase at a constant surface pressure of 20 mJ/m^2, giving a packing density of the fluorochemical at the air/water interface of 65 Å^2/molecule.[4]

The hydrocarbon monolayer (HC) was prepared using a double-chained cationic surfactant dioctadecyl dimethyl ammonium bromide (DODABr) obtained from Aldrich. DODABr was deposited onto mica from an aqueous subphase at a constant surface pressure of 25 mJ/m^2 (corresponding to a packing density of the hydrocarbon at the air/water interface of 68 Å^2/molecule).[5]

The experiments were run at a sliding velocity of 0.8 μm/s and a temperature of 23 °C ± 1 °C. Unless otherwise noted, the ± represents uncertainties of the measured values and refers to one standard deviation of the observed value.

Results and Discussion

Adhesive contact at zero load L was observed between the hydrocarbon monolayer and the fluorocarbon monolayer. A measurable contact area A and friction force F was measured. The measured friction increased monotonically with increasing load and the coefficient of friction $\mu = \delta F/\delta L$ was measured to be 0.027 ± 0.007. The surfaces exhibited smooth sliding - no stick-slip motion was observed.

The friction between two hydrocarbon monolayers was also measured. In this case, stick slip motion was observed. The kinetic friction coefficient was measured to be 0.08 ± 0.01. Clearly, the friction between HC/HC monolayers is much higher than the friction between FC/HC monolayers, at least at this packing density and loading.

In general, the shear stress, $\tau = F/A$, is more applicable for adhesive surfaces than μ. The measured shear stress τ versus pressure, $P=L/A$, is shown in Figure 1. Between HC/HC monolayers, two values for the shear stress are measured at each load. The higher value corresponds to the static shear stress whereas the lower value corresponds to the kinetic shear stress. The shear stress for the FC/HC interface was constant with pressure, at least for pressures below 10 MPa, with $\tau_{FC/HC}$ = 0.2 MPa ± 0.02 MPa. The measured shear stress of the hydrocarbon interface was $\tau_{HC/HC}$ = 0.8 MPa ± 0.1 MPa. The shear stress of the HC/HC monolayers increases with pressure whereas the shear stress of the HC/FC interface remains constant.

Previous studies have measured the friction of fluorocarbon monolayers against similar fluorocarbon monolayers.[6] At velocities greater than 0.001 μm/s, smooth sliding was also attained. The friction, however, was generally *higher* between two fluorocarbon monolayers than the friction between two hydrocarbon monolayers. Hence, the shear stress between surfactant monolayers varies according to: $\tau_{FC/HC} < \tau_{HC/HC} < \tau_{FC/FC}$, at least for the conditions described in these experiments.

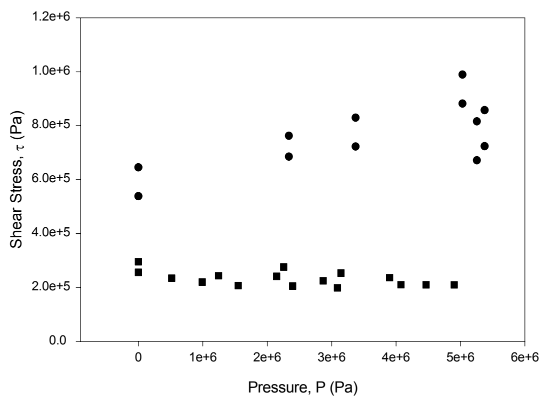

Figure 1. Measured shear stress τ versus load L for a hydrocarbon monolayer slid against a hydrocarbon monolayer (●) and a fluorocarbon monolayer (■). The shear stress is measured to ± 15 %.

Note that the opposite trend is expected in the adhesion force. For nonpolar materials, the reversible work of adhesion W_a between two materials with surface energies γ_1 and γ_2 can be given by $W_a = 2(\gamma_1\gamma_2)^{1/2} \approx 2\gamma_{SV}$, where γ_{SV} is the surface energy of the interface. For fluorocarbon and hydrocarbon surfaces, $\gamma_{FC} = 10 \pm 3$ mJ/m^{2}and $\gamma_{HC} = 26 \pm 4$ mJ/m^2. Thus, the work of adhesion between a hydrocarbon/hydrocarbon surface, hydrocarbon/fluorocarbon surface, and fluorocarbon/fluorocarbon surface is expected to be about 52 mJ/m^2, 32 mJ/m^2, and 20 mJ/m^2, respectively. Hence, the work of adhesion of a FC/HC interface is expected to be intermediate between those of HC/HC and FC/FC interfaces.

The results have implications for industrial issues. In polymer processing, for example, processing aids (antioxidants, fluorochemicals) are routinely added to the polymer prior to extrusion. Some processing aids protect the polymer during high temperatures, such as antioxidants, and others coat the extruder, thereby reducing the interaction of the polymer with the surface. The results presented here show that by coating the extruder, the fluorochemical reduces the shear stress at the extruder surface.

Conclusions

The shear stress between a fluorocarbon monolayer and a hydrocarbon monolayer was measured to be at least 3 times less than the friction measured between fluorocarbon/fluorocarbon and hydrocarbon/hydrocarbon monolayer films. The interaction between the fluorocarbon and hydrocarbon monolayer is *adhesive*, as is predicted from van der Waals dispersive forces.

Disclaimer

Certain commercial equipment, instruments, or material are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology nor does it imply that the materials or equipment are necessarily the best available for the purpose.

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